NASA TECHNICAL MEMORANDUM NASA TM - 75835

AN IMPROVED EVALUATION OF SURFACE FINISH WITH A THREE DIMENSIONAL TESTER

Grandadam -- Prebet -- Riout

NASA-TM-75835 19810013830

Translation of "Le rugiosimetre tridimensionnel pour une meilleure evaluation des etats de surface", Centre d'Etude Technique des Industries Metallurgiques, Senlis, France, Study no. 1.9D.04.0, Report 6, July 20, 1979, 20 pages

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546 JULY 1980

STANDARD TITLE PAGE

1. Report No. TM- 75835	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle AN IMPROVED EVALUATION OF SURFACE FINISH WITH A THREE DIMENSIONAL TESTER		5. Report Date
		6. Performing Organization Code
7. Author(s) Grandadam, Prebet, Riout (CETIM)		8. Performing Organization Report No.
		10. Work Unit No.
9. Performing Organization Name and Address Leo Kanner Associates Redwood City, California 94063		11. Contract or Grant No. NASw-3199
		13. Type of Report and Period Covered Translation
12. Sponsoring Agency Name and Address		14. Sponsoring Agency Code

15. Supplementary Notes

Translation of "Le rugiosimetre tridimensionnel pour une meilleure evaluation des etats de surface", Centre d'Etude Technique des Industries Metallurgiques, Senlis, France, Study no. 1.0D.04.0, Report 6, July 20, 1979, 20 pages

16. Abstract

The design and programming of an automated surface finish tester is described. This device produces a three dimensional image of the microscopic texture of the surface being examined. It is a vast improvement over older types of instruments that can only plot one surface cross section at a time.

17. Key Words (Selected by Author(s))	18. Distribution Statement Unclassified-Unlimited

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages	22. Price

An Improved Evaluation of Surface Finish with a Three Dimensional Tester

Grandadam -- Prebet -- Riout

Centre d'Etude Technique des Industries Metallurgiques
(CETIM)

The common dimensional unit for measuring surface finish is the micron. We are therfore studying a subject of very small size. However, its influence can be found in almost all fields of mechanical engineering. Because dealing with such small dimensions is outside of ordinary human experience, descriptions of surface finish are full of words that evoke the convoluted terrain of the earth's surface: peaks, valleys, craters, plateaus, etc. /1*

The traditional profilometric analyses of surface finish have contributed to the development of the topographic metaphor by magnifying and sometimes considerably distorting the contours found on diagrams of material surfaces. The true profile is visually transformed and represented in a much more controted manner than actually exists. Proportions and especially angles assume staggering sizes.

The microgeometry of a mechanical surface does bear some relationship to the familiar topography of the earth's surface. Like the earth, it also has a three dimensional structure. One of the most common criticisms that is heard of current profilometric methods is that they can only depict one profile of the surface being studied. This is as if one tried to represent the Alps with a single cross section, or to describe them by only giving the altitude of Mount Blanc relative to the deepest valley.

---

*Numbers in the margin indicate pagination in the foreign text.

The traditional representation of surface contours does not state clearly whether a given slope is ascending or descending. The third dimension is missing and without it the real topography cannot be pictured. The assumptions about the surface finish made on the basis of these diagrams are not necessarily reliable for the surface as a whole. To get an accurate idea of the surface, the researcher has to make a large number of dispersed measurements.

The CETIM has developed an automatic tester that can measure and draw three dimensional contours to remedy this state of affairs. The apparatus is described in this article along with the present and future prospects for its utilization.

I. Conventional Profilometry /2

Electronic sensing devices are currently the most popular means of measuring surface contours on mechanical parts. They generally explore a single line crossing the surface and enable the calculation of some of the physical and statistical features of the profile. A graph of this profile can also be plotted.

There is a very large number of models available on the market today. In our three centers, the metrology laboratories posses relatively recent equipment whose general organization is indicated in figure 1.

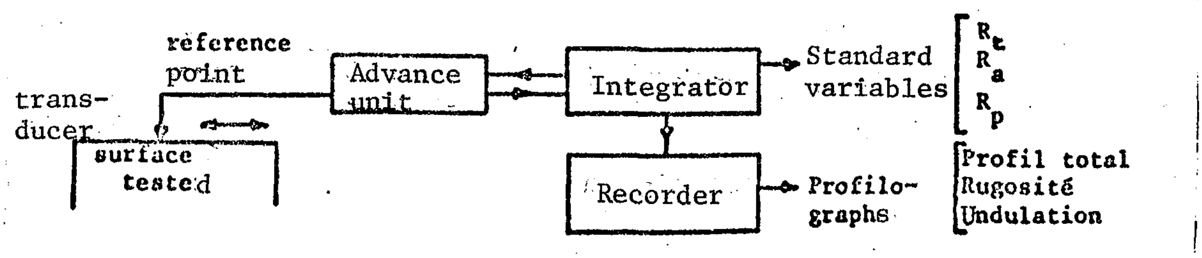


Figure 1
Schematic Diagram of a Conventional Surface Finish Tester

In order to use these apparatuses the following choices and adjustments must be made:

a. Choice of Transducer

The first part of the device is the transducer. The diamond of which it is made is characterized by its form (conical or pyrimidal), its angle (60 or 90 degrees), and the radius of curvature of its point (2 to 10 microns). Contour measurements are made relative to a reference point which could either be exterior to the surface (rectilinear or circular) or obtained by referring to a support piece moving along the same trajectory as the transducer. The support follows the macroscopic features of the surface, and the resulting differential measure reveals the smoothness of the surface finish.

The choice of transducer depends on the degree of precision desired and on the type of finish on the surface being tested. The transducer is actually a mechanical filter.

b. Choice of Area to be Measured /3

The operator has to decide which zone to examine on the surface, and the direction and length of displacement of the tranducer. The French standard NF E 05-15 recommends using the direction that will produce the maximum deviation from the overall form of the piece. The distance over which the probe moves should be dependent on the total dimensions of the surface and the average deviation expected.

c. Truing Up with Respect to an Exterior Reference Line

In this operation, the operator makes the general direction of the profile being examined as parallel as possible to an exterior reference line.

d. Choice of Electric Filter

Measurement with respect to an exterior reference has become more and more widespread. The separation of the various categories of surface roughness is made by means of electric filters. The choice of the proper filter is certainly the most semsitive decision made. It is based on the choice of cut off wavelength. Both high-pass (allowing high frequencies through) and low-pass filters are used. There is never a clear-cut separation. If the different categories of unevenness that have to be separated are of nearly the same average wavelength, a complete separation is almost impossible.

The choice of filters is fundamental. It determines the appearance of the roughness and cyclical variation profiles as well as the value of the standardized parameters. This is why the specification of surface finish should always be accompanied by the type of filter used for its evaluation.

The ISO recommends the following wavelength limits for high-pass filters: 25, 8, 2.5, 0.8, 0.25, and 0.08 mm. The most common filters (8, 2.5, and 0.8 mm) are available on the numerous models presently in use. Choice between them is usually related to the length of the test line. On the latest models the range of filters has been extended and has become independent of the profile length that has been chosen.

The French standard NF E 05-015 classifies surface irregularities into four categories:

First Order: Irregularities in basic surface configuration.

In general, surface finish testers cannon analyze these irregularities. The only exception is that some devices can measure uneveness within the test line. (120 mm is the maximum length.)

Second Order: Cyclic irregularities in surface finish.

These divergencies usually have a periodic character. They are most often due to low frequency vibrations in the part during machining and/or in the machine tool itself.

Third Order: Grooves and scoring.

Fourth Order: Scratches, tool marks, pitting, etc.

The general name for third and fourth order irregularities is "roughness". It has multiple causes including high frequency vibrations in the machine setup.

Three different types of profiles have traditionally been distinguished. (See figure 2.) These are the total profile containing all the irregularities from the first to fourth orders; the cyclical profile depicting second order irregularities; and the surface roughness profile including third and fourth order irregularities. It should be noted that for the last two types of profiles, the next lowest order irregularity serves as the reference line.

/5

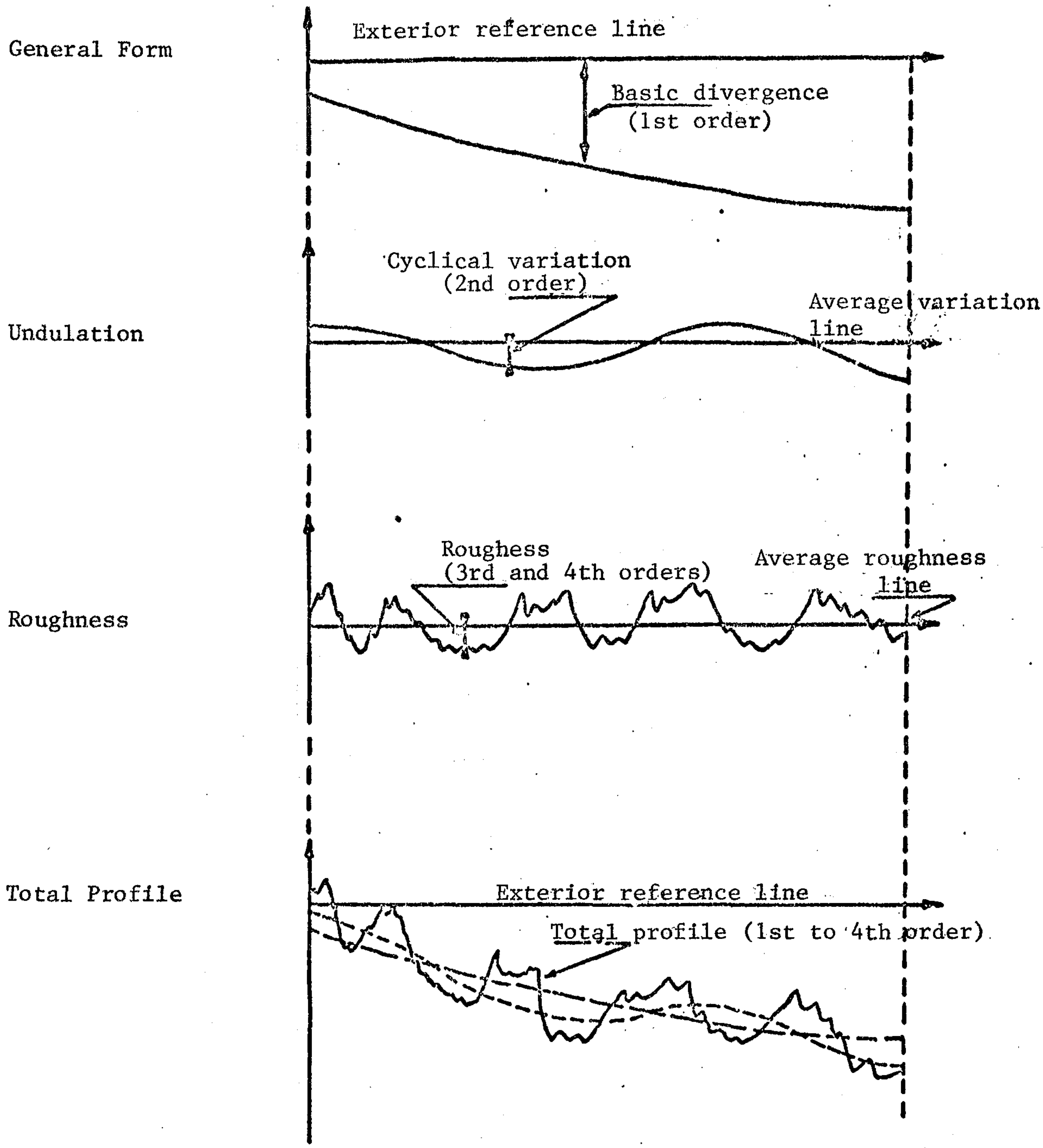


Figure 2
The Four Categories of Surface Uneveness

Appendix 2: Roughness Parameters

For each type of surface finish diagram (total, cyclical variations, surface roughness), the French standard NF E 05-015 defines several physical or statistical parameters. Below are the definitions of the three rounghess parameters currently in use. (See figure 3.)

$R_t = (z_R)_{max} - (z_R)_{min}$, total depth, or total amplitude, of roughness.

$R_p = \frac{1}{L} \int_0^L (z_R) dx_R$, average depth of the surface roughness profile.

$R_a = \frac{1}{L} \int_0^L |z_R - R_p| \, dx_R$, arithmetic average of the roughness amplitude.

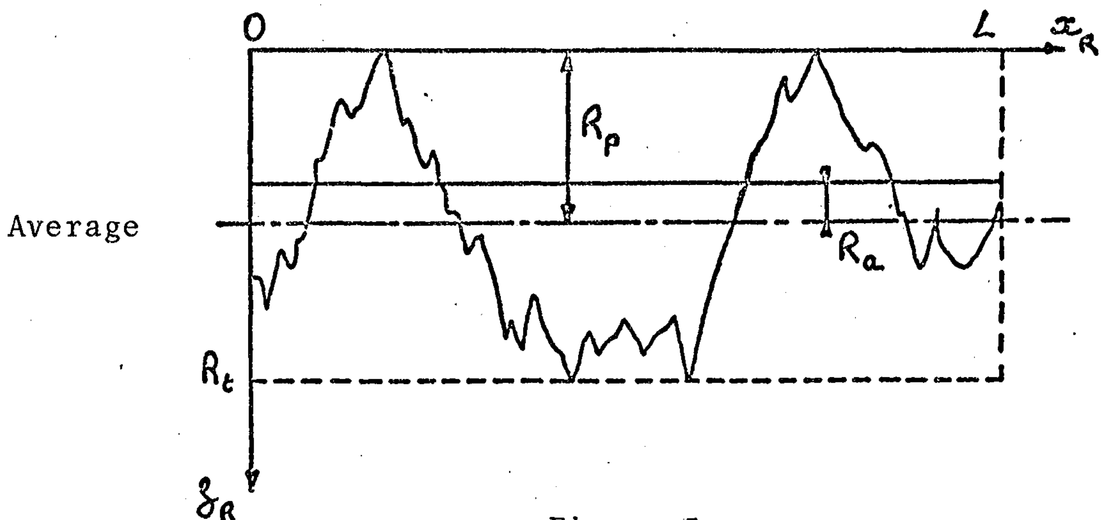


Figure 3
Surface Roughness

The definitions of surface roughness and cyclical variation profiles have been standardized. They are based on separators capable of extracting any given component of the total profile. In sensor equipped electronic apparatus, electric filters fulfill this function.

An electric filter is characterized by its gain curve and, more specifically, its cutoff wavelength. Figure 4 shows the gain curve of a high-pass electric filter with a cutoff wavelength λ_{fph} (expressed in millimeters).

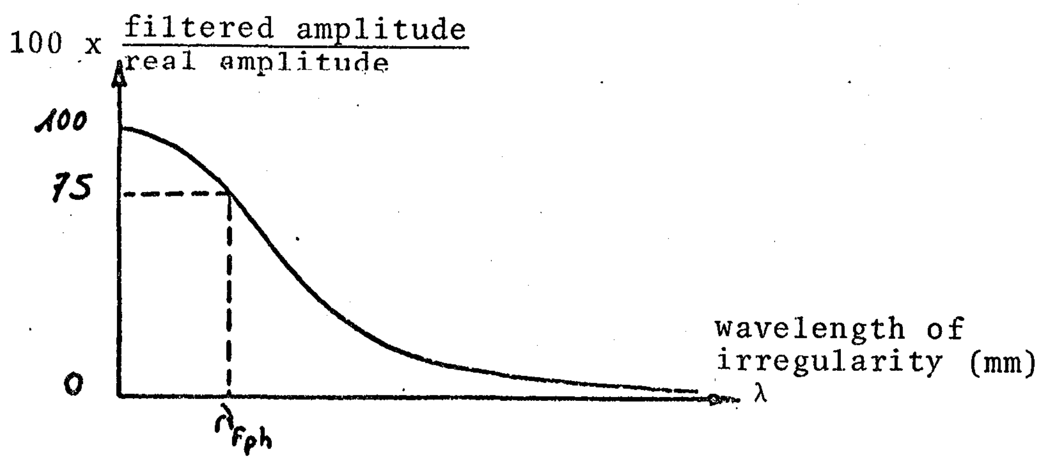


Figure 4
Gain Curve of a High-Pass Electrical Filter

The cutoff wavelength suffers a 25% reduction of amplitude when passing through the filter. Smaller wavelengths are reproduced more accurately whereas longer wavelengths are even more attenuated. The greater the slope of the gain curve, the greater the separation. The slope is usally around 12 decibels per octave. Irregularities caused by roughness and cyclic variations are separable in proportion to the difference between their average values.

III. A Three Dimensional Surface Finish Tester

/8

A few years ago, our Saint Etienne branch built a prototype three dimensional surface finish tester. (See CETIM-informations, no. 43, December 1975, page 6.)

This apparatus has been completely reconstructed in order to increase its performance and flexibility. The new equipment, which was also built at Saint Etienne, is now in service in our demensional metrology laboratories at Saint Etienne and Senlis.

The development of the new tester was based on the conventional design as described above. Figures 5, 6, and 7 show its principal components: a programmable calculator, a digital voltmeter, a table that is movable along both the X and Y axis, a translator for this table, and a digital two dimensional plotting table.

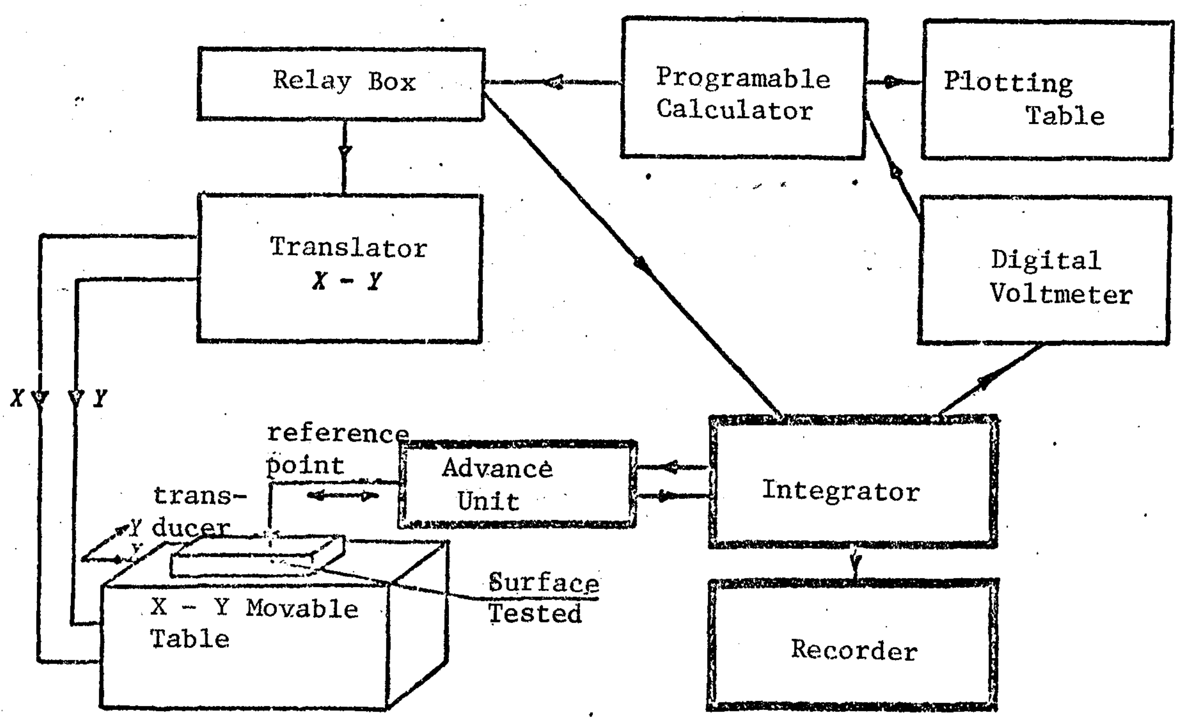
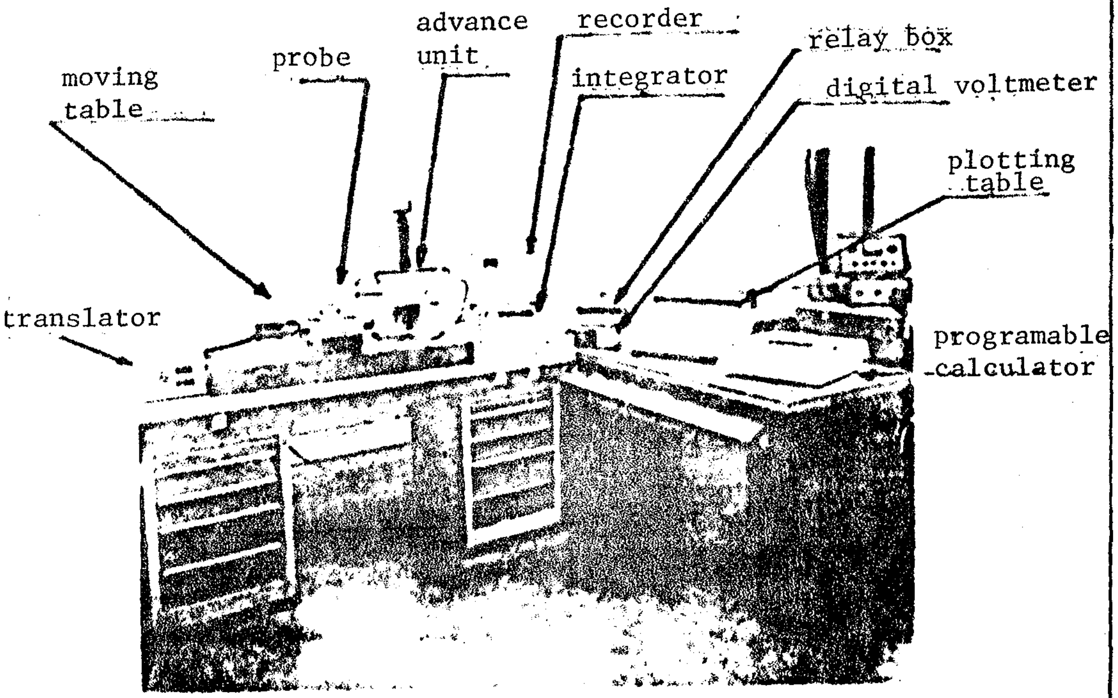
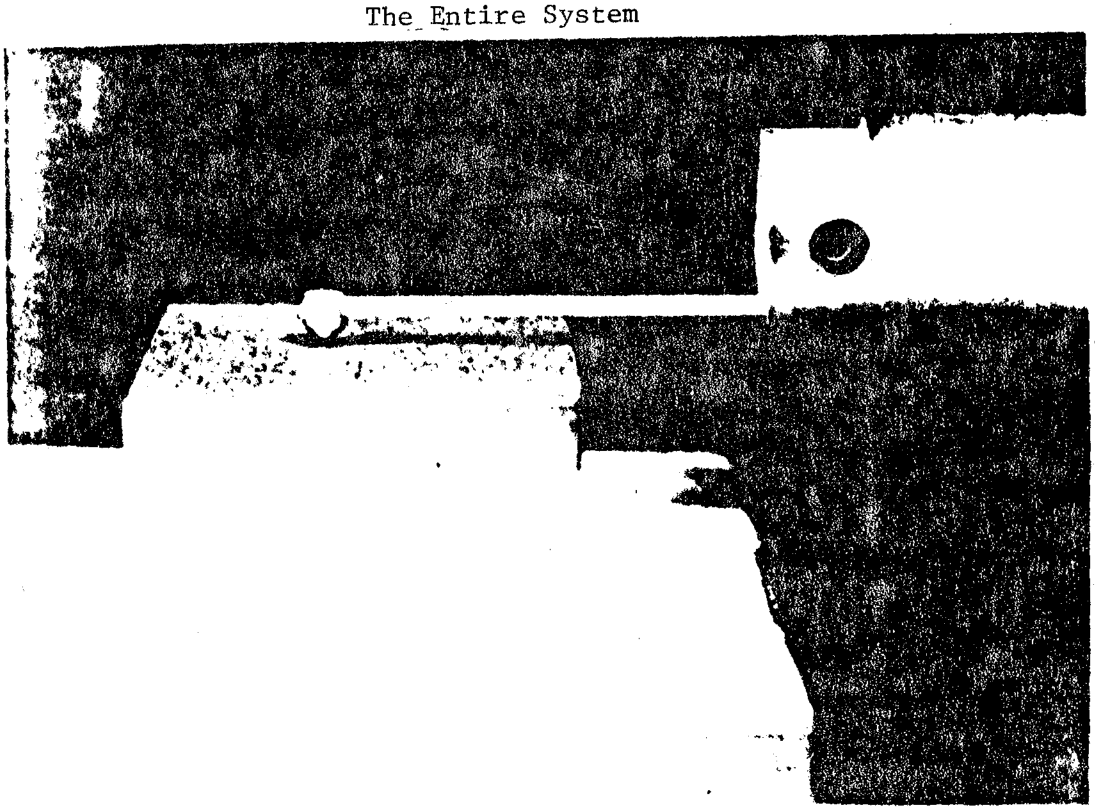


Figure 5
Schematic Diagram of a Three Dimensional Surface Finish Tester



The Entire System



Transducer

Figure 6

Figure 7
Photomicrograph of a Conical Transducer
(90^{o} angle, 3 micron point radius)
Magnification: 380X

The basic surface finish tester is adjusted in the regular fashion. Then the necessary data and measurement parameters are introduced into the programmable claculator, which runs the entire system automatically. This includes displacing the trandsducer; commanding the translator to move the surface being examined between profiles; manipulating the measurements and roughness profiles as required; and controlling the plotting table to make a representation of the surface that shows perspective. /11

The calculator program is witten in a conversational language and is stored on magnetic tapes. The movable table, commanded by the translator is displaced along the X and Y axis by incremental motors (1 micron minimum). The largest area that can be covered is 100 by 150 millimeters. The contours sensed by the tranducer are converted to digital signals by the voltmeter and sent to the plotting table.

We have written a preliminary program that permits:

-- The measurement of a large number of parallel profiles.

-- The recording on paper tapes of the parameters R_t, R_a, and R_p, as calculated by the integrator for each profile.

-- The calculation of the maximum, minimum, and average values of the surface roughness parameters over the entire surface tested, as well as the average deviation of these parameters.

-- A graphical three dimensional representation of the surface texture (maximum format: 250 x 375 mm) that can show perspective. Also, the automatic determination of the scales and amplification factors in effect for all three axes.

The program follows the flow chart displayed in figure 8.

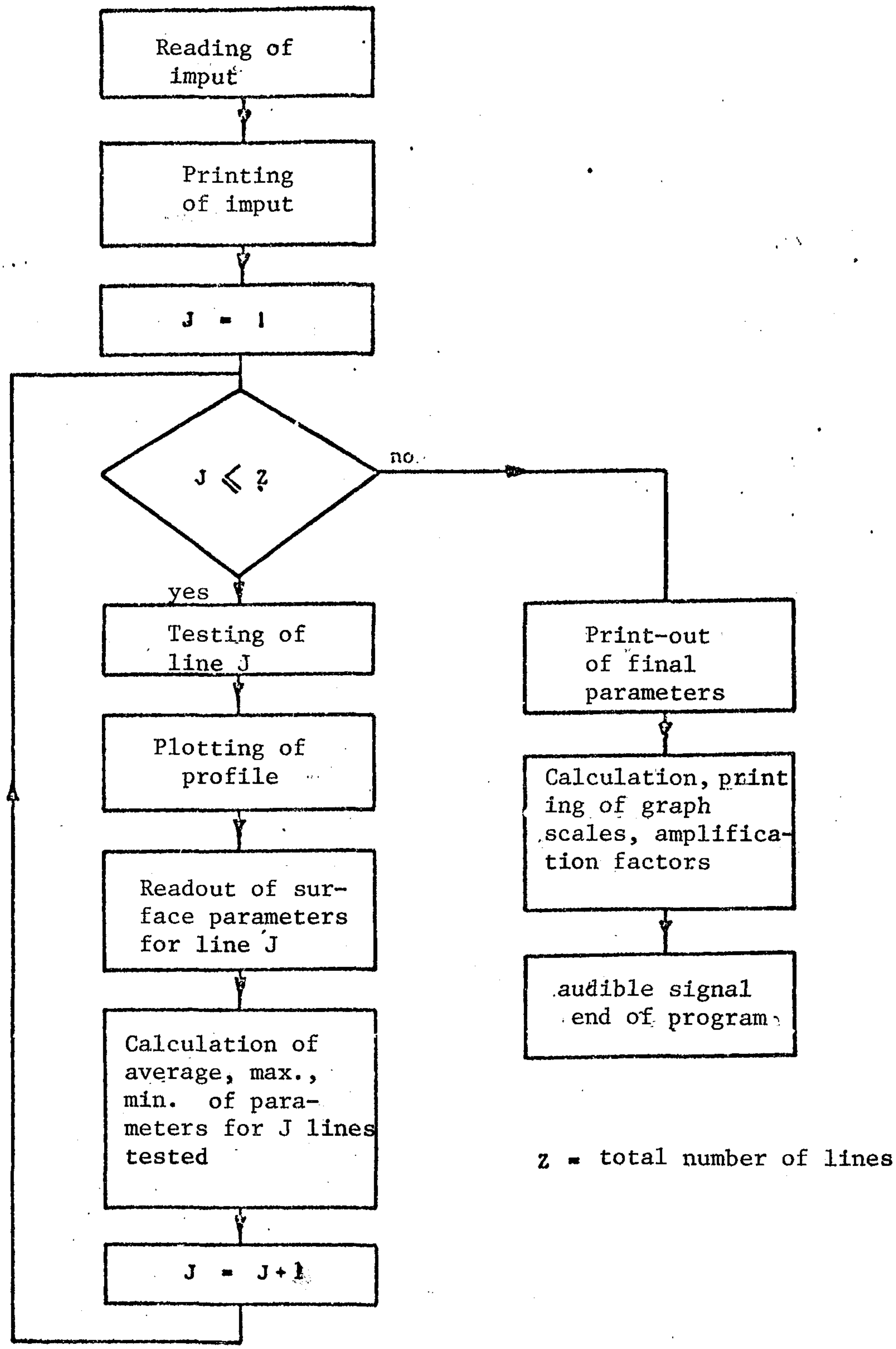


Figure 8

Flow Chart of Preliminary Program

/13

As an example, we demonstrate below the use of the program on a milled surface. During the operation, the printer of the programmable calculator sucessively prints the data typed in on the keyboard, the parameter read-out for each line, and finally the total results. At the same time, a diagram of the surface is drawn by the plotting table. The three dimensional representation in figure 12 can be compared with the conventional profilogram displayed in figure 13.

```
Date :
"20/06/79"

Type de  piece :
"Echantillon Aci
er Inox"

Mode d usinage :
"Fraisage"

Reference du pal
peur :
"BFRW 750/10"
```

```
DONNEES:

Code palpeur [1
ou 10]:T?
10
Longueur de palp
age [en mm]:C?
15
Longueur d evalu
ation [en mm] :
              12
Vitesse palpage
[en mm/s]:D?
.5

Cut-off[en mm]?
2.5
Echelle vertical
e graphique Pert
hen [en micron/c
m]:H?
25

Increment X [en
micron]:P?
30
Increment Y [en
micron]:Q?
120
Code deplacement
 table/X[1 ou 2]
:R?
1
Code deplacement
 table/Y[4 ou 8]
:S?
4

Nombre  points
echantillonnage:
N?
450
Nb de lignes:Z?
70
Increment  sur
graphique[en mm]
:E?
3
Amplification se
lon X sur graphi
que :M?
25
```

Figure 9a

Calculator Imput

Date:
"06/20/79"

Type of part:
"Stainless Steel
Sample"

How machined:
"Milled"

Transducer
model no.:
"BFRW 750/10"

IMPUT:

Transducer code
(1 or 10):T?
10
Test Length
(in mm):C?
15
Evaluation length
(in mm):
12
Test speed
(in mm/s):D?
.5

Cutoff (in mm)?
2.5
Vertical diagram
scale (in microns/
cm):H?
25

X increment
(in microns):P?
30
Y increment
(in microns):Q?
120
Table displacemnt
code/X (1 or 2):R?
1
Table displacement
code/Y (4 or 8):S?
4

Number of points
checked:N?
450
No. of lines:Z?
70
Diagram increment
(in mm):E?
3
X axis diagram
amplification:M?
25

Figure 9b
Translation of Figure 9a

VALEUR CRITERES
PAR LIGNE[en mic
ron]:

	1
Rt=	23.40
Ra=	3.50
Rp=	5.80
	2
Rt=	23.00
Ra=	3.60
Rp=	5.70
	3
Rt=	23.00
Ra=	3.60
Rp=	5.60
	4
Rt=	23.20
Ra=	3.60
Rp=	5.70
	5
Rt=	23.00
Ra=	3.60
Rp=	5.80
	6
Rt=	22.80
Ra=	3.60
Rp=	5.70
	7
Rt=	22.70
Ra=	3.70
Rp=	5.70
	8
Rt=	22.50
Ra=	3.60
Rp=	5.80
	9
Rt=	23.00
Ra=	3.50
Rp=	5.90
	10
Rt=	23.20
Ra=	3.60
Rp=	5.80

Figure 10
Calculator Output
Parameter Values
per Line
(in microns)

/15

Only the data for the first ten lines are presented here.

```
a VALEUR CRITERES
  GLOBAUX:

b Rt[moyen]= 23.04
  Rt[maxi]=  24.60
  Rt[mini]=  21.80
ç Ecart-type Rt=
               0.67

b Ra[moyen]=  3.65
  Ra[maxi]=   3.80
  Ra[mini]=   3.50
c Ecart-type Ra=
               0.07

b Rp[moyen]=  5.62
  Rp[maxi]=   6.20
  Rp[mini]=   5.00
c Ecart-type Rp=
               0.30

d ECHELLE GRAPHIQU
  E [en micron/cm]
  :
e selon X       400

f selon Y       400

g selon Z        10

h AMPLIFICATION GR
  APHIQUE:

e selon X        25

f selon Y        25

g selon Z      1000
```

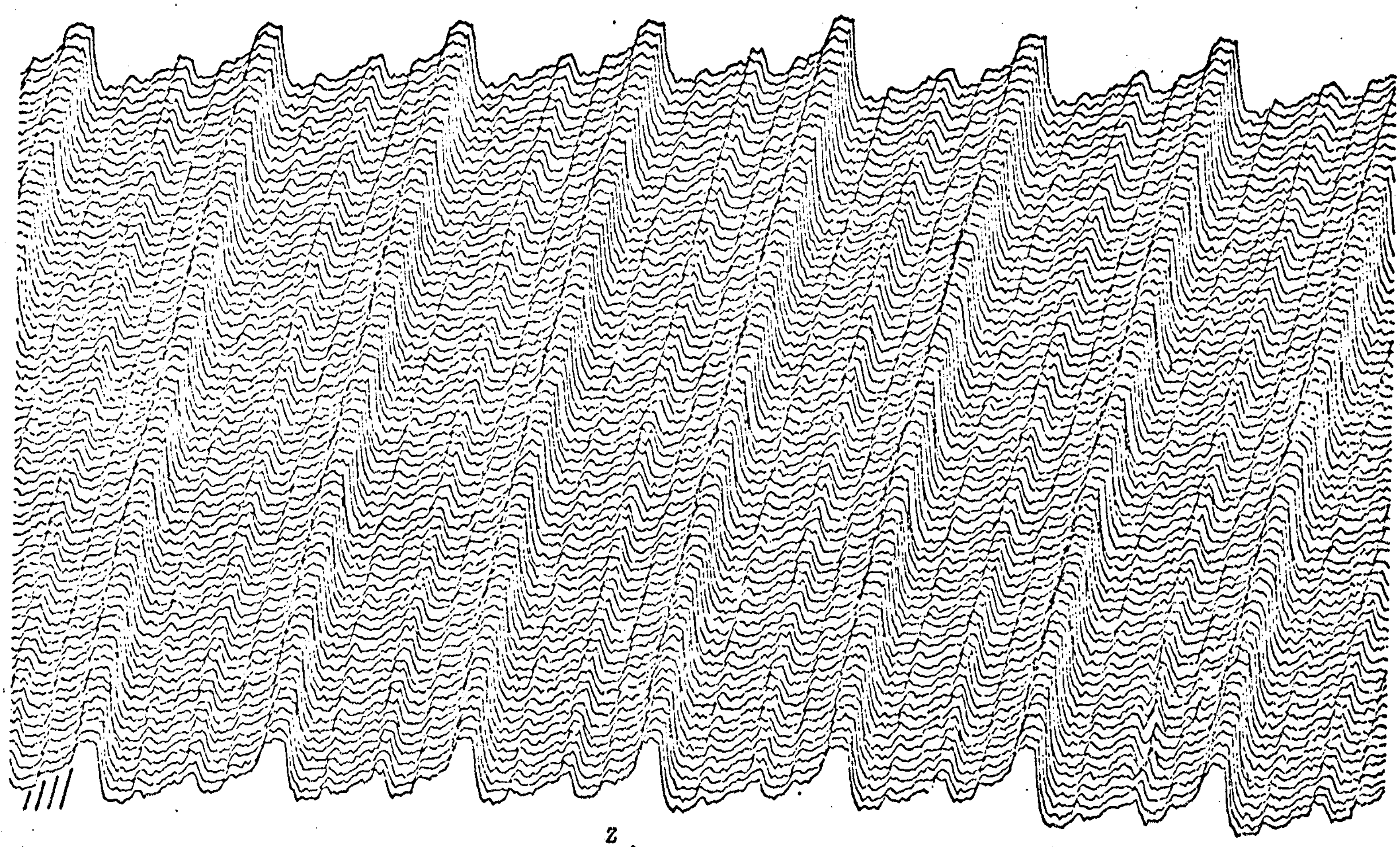
Figure 11

Final Results

It is evident from the small average deviations that the surface under examination is very homogeneous.

The amplification of surface features is the same along the X and the Y axes. (The X axis is the direction in which the transducer is moved. Y is perpendicular to this direction.) The amplification along the Z axis (perpendicular to the surface) is forty times greater. Therefore, the distortion factor $C_{anamorphosis} = 40$.

Key: a) Value of overall parameters
- b) (average)
- c) Average deviation
- d) Scale of graph (microns/cm)
- e) Along the X axis
- f) Along the Y axis
- g) Along the Z axis
- h) Amplification factor



Original dimensions of
image: 375 x 210 mm
Test surface: 15 x 8.4 mm
70 profiles 120 microns apart

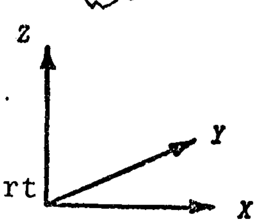


Figure 12
Three Dimensional Representation

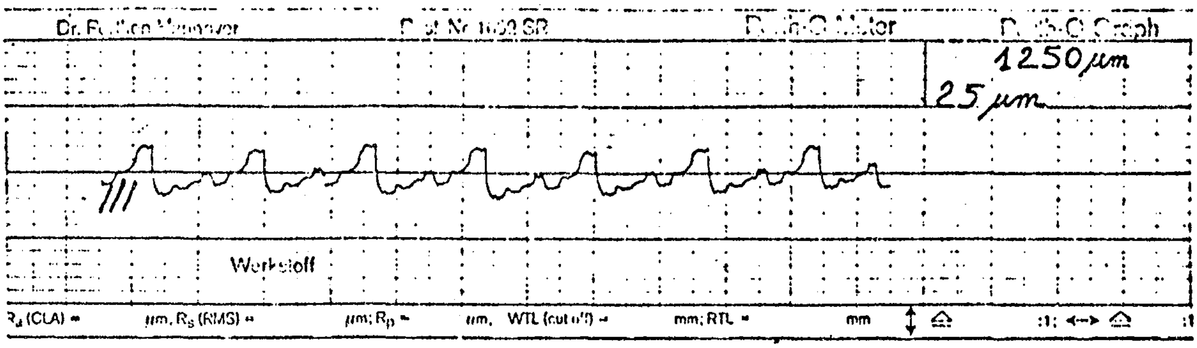


Figure 13
Conventional Profilogram

On this graph the magnification along the X axis is 8 times and along the Z axis 400 times.

$C_{anamorphosis} = 50$

III. The Capabilities of the Three Dimensional Surface Finish Tester /19

The three dimensional surface finish tester presents the following advantages over conventional profilometry:

-- A more complete exploration of surface texture by successive probe sweeps.

-- Automation of measuring and calculating.

-- A more accurate representation of the derived parameters.

-- An analysis of the degree of homogeneity of the surface (by examining the standard derived parameters).

-- A three dimensional graphic representation that accurately depicts the state of the surface.

-- Detection of local imperfections.

-- Detection of scoring that ocurred during machining.

Aside from the features listed above, the apparatus as it is presently constructed allows the following activities to be carried out:

-- The calculation of all the French standard parameters (there are 18) as well as general shape characteristics.

-- The calculation of new parameters as required.

-- The plotting of density curves for the distribution of profile heights, slopes, curvatures, etc.

-- The plotting of lift curves.

More complete workups are also possible through the use of a computer. In particular, this would permit:

- -- Fourier analyses.
- -- The plotting of power spectrum density curves.
- -- The plotting of autocorrelograms.
- -- The calculation of surface parameters.

The range of possibilities is obviously immense. This is due to the highly flexible nature of the equipment that has been developed.

Appendix 5: French Standards for Surface Finish

/20

Regulations concerning surface finish on products:

1) General descriptions, terminology, definitions: AFNOR, NF E 05-015, 1972

2) Specification of surface finish on blueprints: AFNOR, NF E 05-016, 1972

3) Surface finish classification: AFNOR, NF E 05-017, 1972

4) Economic factors: AFNOR, NF E 05-018, 1972

Measurement procedures and visual-tactile samples for comparison of surface finish: AFNOR, NF E 05-051, 1972